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WILLISTON BASIN PROFILE, SOUTHEAST SASKATCHEWAN AND SOUTHWEST MANITOBA: A WINDOW ON BASEMENT-SEDIMENTARY COVER INTERACTION

J.R. Dietrich, J.A. Majorowicz and M.D. Thomas

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INTRODUCTION

The Williston Basin has substantial proven hydrocarbon resources and recent oil discoveries in Ordovician strata in southeast Saskatchewan indicate the considerable potential for plays and prospects in deeper parts of the basin. All deep oil pools discovered to date have some linkage to basement structure, indicating the need for regional analyses of basement-sedimentary cover relationships. This report presents a regional profile of the basin in southern Saskatchewan and Manitoba, outlining important basement-cover linkages. The profile incorporates information from exploration wells and gravity, magnetic, seismic reflection and refraction, electromagnetic, and geothermal data. The profile provides a comprehensive integration of sedimentary geology and crustal geophysical characteristics of the Williston Basin in Canada.

The 300 km-long, E-W profile (***Figure 1***) extends from Range 21W1 (near Brandon, Manitoba) to Range 18W2 (southeast of Regina)(~100 to 104.5°W : 49°30'N), traversing a large segment of the northern Williston Basin (***Figure 2***). The sedimentary portion of the profile was derived from a composite of stratigraphic information from deep wells, including 11 drilled to Precambrian, and petroleum industry seismic reflection lines (including data from Zhu, 1992; Redly, 1998; Dietrich and Magnusson, 1998) within a 40 km wide corridor (~ Townships 4 to 7). The sub-Phanerozoic crustal portion was derived from a compilation of published crustal seismic refraction data (Green *et al*., 1980; Delandro and Moon, 1982; Morel a l'Hussier *et al*., 1987), deep reflection data (Green *et al*., 1985), and electromagnetic data (Jones and Craven, 1990). The accompanying geophysical profiles illustrate gravity, magnetic and heat flow anomalies. The gravity and magnetic profiles (***Figure 1***) and maps (***Figure 3***) were derived from the National Geophysical Database of the Geological Survey of Canada. The heat flow profile (***Figure 1***) and geothermal maps (***Figure 4***) were derived from analyses of bottom-hole temperature and conductivity data from several hundred wells. The heat flow profile depicts a trend curve (7^{th} order polynomial fit) of heat flow calculations from 31 wells along the profile.

The sedimentary profile depicts lower Mesozoic and Paleozoic strata, unconformably overlying Precambrian crystalline basement (uppermost parts of the basin are not displayed). The profile is displayed using an upper Cretaceous datum, except for the South Regina Trough where a surface datum is utilized to account for post-Cretaceous salt dissolution structure. No absolute depth scale is indicated. Basement depths in the profile corridor range from 1500 to 3000 m subsurface (***Figure 2***). The profile is annotated with lower Paleozoic oil pools/shows, feature areas (numbers keyed to text), and selected areal trends of basement and sedimentary cover elements. The profile is designed to illustrate the general style and scale of Paleozoic basin elements as they relate spatially to basement domains and geophysical anomalies. It is not intended to depict all features of possible petroleum exploration significance.

PROFILE ANALYSIS

Precambrian crystalline basement beneath the Williston Basin in Canada is composed of a complex mosaic of lithotectonic domains (Green *et al*. 1980, 1985; Collerson *et al*., 1990; Burwash *et al*., 1993; Lyatsky *et al.* 1998). Fundamental crustal elements within the profile area include the Churchill-Superior Boundary Zone, Tabbernor Fault Zone (separating eastern and western segments of the Trans-Hudson Orogen) and Swift Current Province margin (***Figures 2, 3***). The profile crosses the full width of the Early Proterozoic Trans-Hudson Orogen tectonic belt (~200 km wide at the profile latitude).

The Churchill-Superior Boundary Zone (CSBZ) in southwest Manitoba is a 40-60 km wide Early Proterozoic crustal suture zone separating Archean rocks of the Superior Province from Proterozoic-Archean rocks of the Trans-Hudson Orogen. In the profile area, the N-S aligned CSBZ is geophysically marked by a magnetic anomaly high and broad low, a gravity high-low pair, and high heat flow; the zone contains a steep dipping crustal conductivity anomaly (Thompson Belt conductor), an upper crustal high velocity lid, and a lower crustal (velocity) ramp. The basement surface within the eastern CSBZ is disrupted by faults and a low-angle, west-side-down hinge zone. The CSBZ is directly overlain by a major Phanerozoic salt dissolution trend, the Birdtail-Waskada Zone. The location and origin of the (Prairie Formation) salt dissolution zone appears linked to basement faulting (Dietrich and Magnusson, 1998). Activation of basement-connected faults may have disrupted basin hydrodynamic patterns, influencing salt dissolution. Much of the dissolution in the zone occurred during late Paleozoic time. The eastern CSBZ hinge/fault zone also appears to have controlled Middle Devonian Winnipegosis shelf edge development (1) and Ordovician lithofacies and porosity patterns (2) (Dietrich and Magnusson, 1998). The transition from the CSBZ into the eastern Trans-Hudson tectonic belt is marked by a gravity high and upper crustal velocity anomaly (fault?). This zone coincides with a basement-surface fault and flexure zone. This boundary coincides with the western limit of significant (salt-related) upper Paleozoic structure. Variations in basement-surface slopes across the margin may have controlled development of an Ordovician Red River oolite bank (3) (Christopher *et al.,* 1971).

The Tabbernor Fault Zone (TFZ) in the central Trans-Hudson Orogen is a regional crustal shear zone with a protracted Early Proterozoic to Phanerozoic deformation history (Elliot, 1995). In the profile area, the TFZ is geophysically marked by a steep magnetic gradient zone, separating two regionally distinctive magnetic domains (***Figures 1, 3***). The TFZ coincides with the eastern limit of the North American Central Plains (NACP) anomaly, a broad, arcuate-shaped conductor within the mid crust. The NNE-aligned TFZ appears to coincide with a broad, low-relief flexure of the basement-surface and overlying lower Paleozoic cover (Alameda Flexure Zone (AFZ)). The flexure zone is locally disrupted by small-scale basement faults. The AFZ anticlinal zone is associated with an abundance of Winnipegosis reefs (4) and an Ordovician reef (5) (Pratt *et al*., 1996), suggesting basement paleo-topographic influences on reef development. The eastern side of the AFZ coincides with a Cambrian fault or escarpment bounding a Deadwood half-graben/depocentre (6). Magnetic anomaly trends indicate this feature may be oriented NW-SE, oblique to the main TFZ trend.

The western Trans-Hudson Orogen (THO) is marked by low amplitude magnetic anomalies, and gravity and heat flow highs coincident with the NACP crustal conductor. The western THO domain contains the highest relief basement-surface structures in the profile region (local highs with up to 100 m vertical relief (7)), and contains most of the known Ordovician oil pools, including the Weir Hill and Midale basement fault block/anticline traps (8, 9). Thinning of Cambro-Ordovician strata over many structures indicates syndepositional basement relief. A spatial association is observed between an Ordovician lithofacies transition (source rock subbasin edge (10) (Stasiuk and Osadetz, 1990)) and a subtle basement hinge zone. Most geophysical anomalies and deep basin features in the western THO trend NNW-SSE (***Figures 1, 2, 4***). The N-S aligned Nesson anticline in North Dakota (***Figure 2***) occurs in this tectonic domain.

The Swift Current Province (SCP) is an Early Proterozoic, anorogenic plutonic belt that overprints the Trans-Hudson Orogen in southwestern Saskatchewan (Collerson *et al*., 1990). The eastern margin of the SCP is marked by a magnetic low, eastward thinning mid-crustal low velocity zones, a lower crustal (velocity) ramp, and a westward-deepening Moho. The crustal transition is spatially associated with east margin of South Regina-Hummingbird Trough (ST), a regional salt dissolution zone. The dissolution zone generally parallels the NNW-aligned crustal margin, though local salt-edge segments also trend NNE (***Figures 1, 2***). Basement-connected faults in the ST indicate possible fault control on dissolution processes. Dissolution occurred in multiple phases, with a significant late-stage (post-Mesozoic) component. The SCP margin is also closely aligned with the western margin of the Winnipegosis shelf (11) (***Figure 2***), suggesting basement control. The shelf margin is associated with an intra-sedimentary fold, close to the basin centre.

CONCLUSIONS

The profile outlines a diverse spectrum of basement-cover associations and provides some insights into a complex history of basement influence on basin evolution. Spatial and probable genetic associations occur between Precambrian tectonic boundaries and regional Paleozoic depositional, structural and salt dissolution trends. Though basement-related basin structures are relatively small in amplitude, they are important for petroleum plays within the lower Paleozoic section. Possible new or under-explored plays (noted here) include Cambrian Deadwood sandstones (half-grabens in TFZ area), Ordovician Winnipeg sandstones (basement highs and hinge zones), Ordovician Red River oolite bank (western CSBZ margin), and upper Paleozoic strata above salt front rollover (western BWZ margin).

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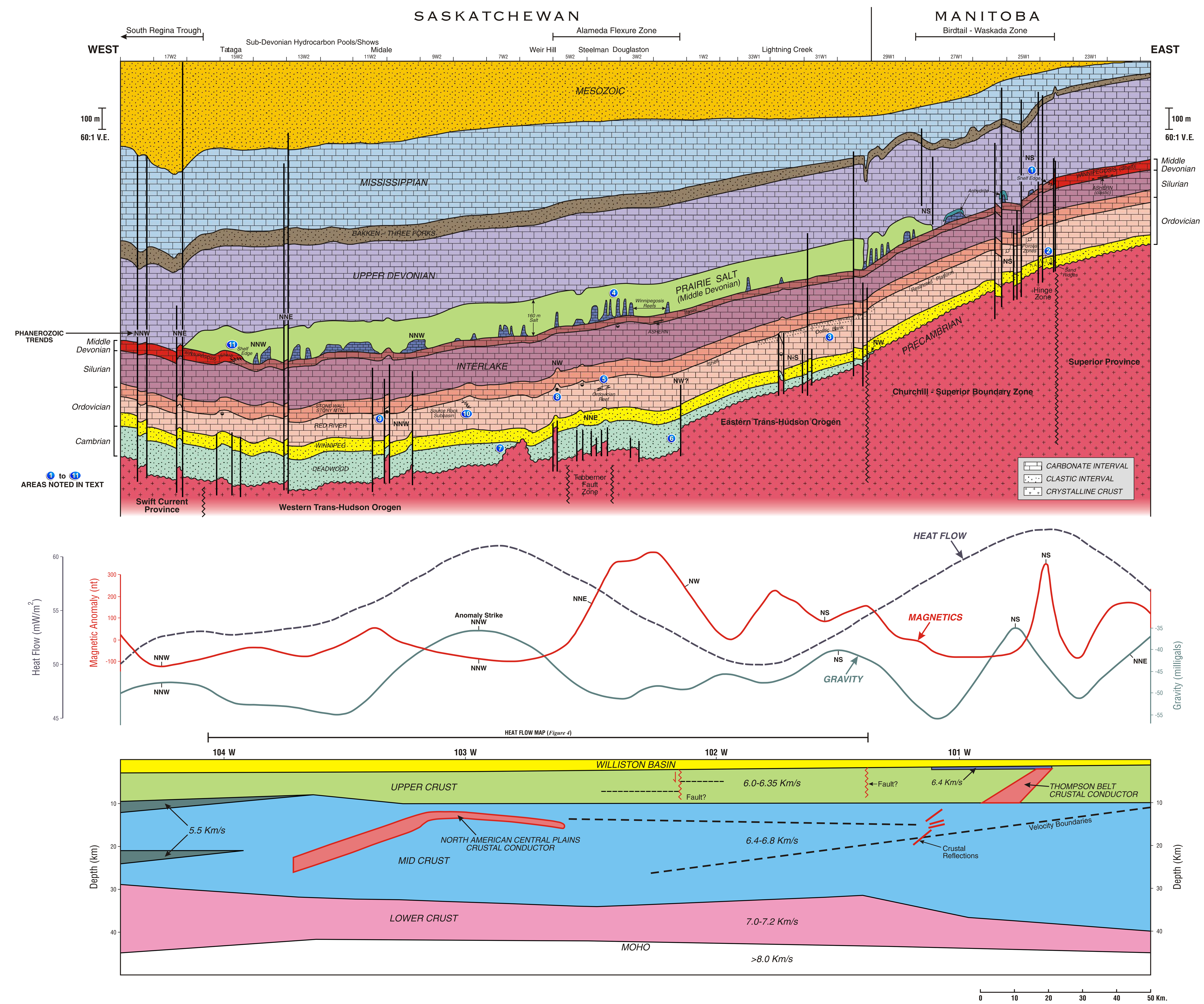

Figure 1: Williston Basin sedimentary and crustal profile, southeast Saskatchewan - southwest Manitoba.

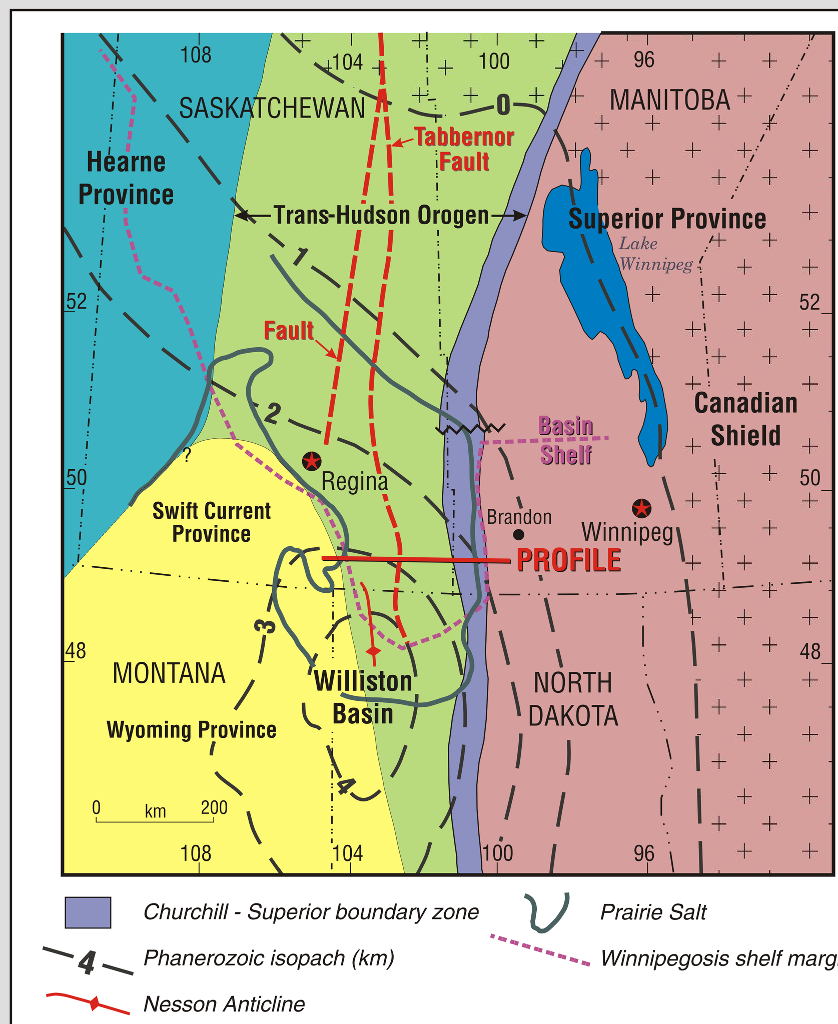

Figure 2: Profile location map with Precambrian tectonic provinces and regional faults (interpreted from aeromagnetic data), Williston Basin outline, and limits of Middle Devonian Prairie salt and Winnipegosis shelf.

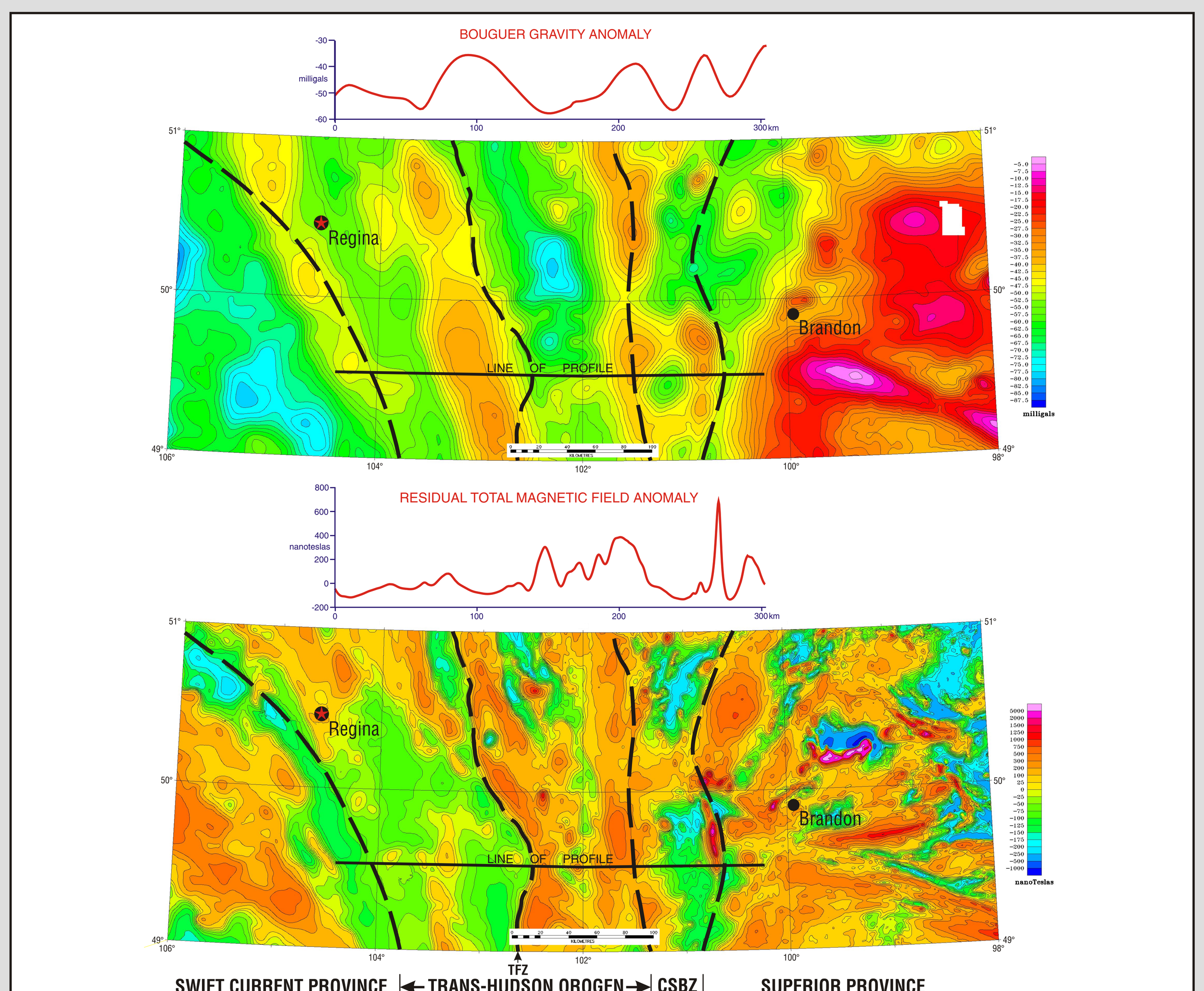

Figure 3: Gravity and magnetic anomaly maps. Dashed lines indicate approximate positions of main Precambrian tectonic boundaries. Solid line indicates profile location. **TFZ** – Tabbernor Fault Zone; **CSBZ** – Churchill-Superior Boundary Zone.

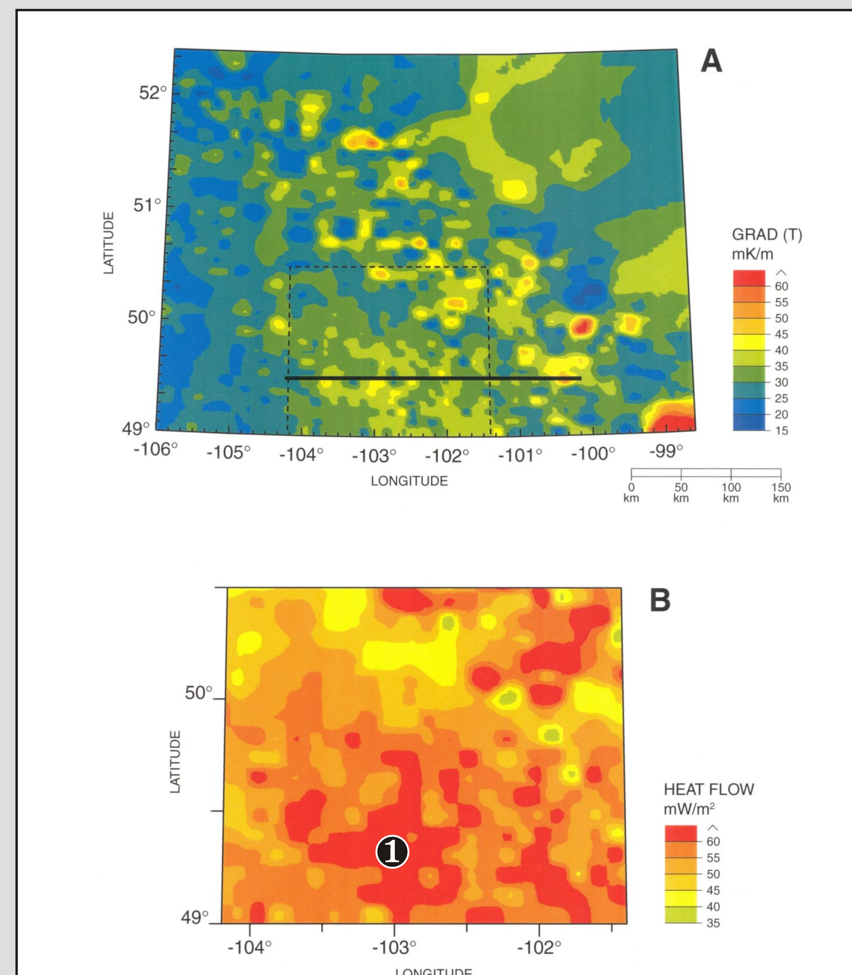

Figure 4: Geothermal (**A**) and heat flow (**B**) maps. Solid line in top map indicates profile location; dashed line outlines area of heat flow map. NNW-SE anomaly trends parallel basin isopachs, reflecting depth-conductivity variations in basin strata. The northerly trending heat flow high (**1**) coincides with the NACP conductor location (***Figure 1***) and is probably a crustal-source anomaly.